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PERFORMANCE MEASUREMENT

IN THE

MANUFACTURING UNIT

A THESIS

Presented to

The Faculty of the Graduate Division

by

James M. Apple, Jr.

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Industrial Engineering

Georgia Institute of Technology

May, 1968

PERFORMANCE MEASUREMENT

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MANUFACTURING UNIT

Approved:

Chairman

Date approved by Chairman: 5-31-68

PREFACE

PERFORMANCE MEASUREMENT AS OPPOSED TO WORK MEASUREMENT

Because of the misunderstanding that always seems to be present concerning this thesis topic, it seems important to make a distinction between the subject matter here and the field of work measurement. The confusion of the two is easily understandable since work measurement is an integral part of performance measurement. As commonly studied, work measurement refers to the detailed study of an operation to assess its human work content. The results of work measurement are used to determine a standard time for an operation and within the field there is a term, performance, which refers to the gross output over a period of time divided by the output expected according to the standard. Performance measurement, as discussed in this thesis, refers to this same performance, but in a much more aggregate form. Performance will be a comparison between the actual effort in men, materials, and machines required to produce a specified result and the effort which is estimated to be required if all tasks are performed in a prescribed manner. Here we will be concerned with the performance not of individuals, but of entire manufacturing units.

ACKNOWLEDGMENTS

I should like to take this opportunity to express my gratitude to the following people who helped to make this thesis a reality:

My advisor, Dr. J. Gordon Davis, for those grueling sessions required to find the loopholes in my approach, and to Drs. L. A. Johnson and R. G. Gamoneda for their helpful suggestions and comments.

Those men in the Methods Engineering Department at Oldsmobile Division of General Motors who contributed so much to my education in the real world and with whom I developed an interest in the behavior of an entire manufacturing unit.

Mrs. Barbara Harden for the excellent typing which perhaps adds more style to my words than they deserve.

My wife, Mary Audrey, without whose constant encouragement I never would have finished and who undertook to transliterate my penmanship to English.

Finally and most importantly to my Father and unofficial member of my thesis committee, James M. Apple, who forced me to meet his expectations rather than to compromise when the problems seemed insurmountable.

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CHAPTER I

INTRODUCTION

Objective and Intent

The initial intent of this thesis research was to develop a general model to act as an index of performance for the entire manufacturing function of an enterprise. It was hoped that it would be possible to survey the works of others regarding performance measurement and to continue from their assumption that an overall measure for an operating unit is a desirable and needed tool for management control. Unfortunately, although performance measurement is far from being a new field, the literature is restricted primarily to the evaluation of individual variables. In some isolated instances the problem of overall performance is discussed. Most often, however, it is in terms of the whole company - sales, financing, and general administration included. In no case is there a firm establishment of the need and uses for a single measure. As a consequence, the goals of this research have been somewhat redirected toward an attempt to set forth the conditions which dictate the need for a single value as a measure of the performance of the manufacturing unit. With this need established, possible approaches to the development of the measure and the problems to be overcome in them will be discussed.

History of Performance Measures

In the broadest sense, performance measurement has existed as long as man has set out to accomplish a specific task. In deciding what course of action to pursue he necessarily visualized some end result. The comparison of this expectation with the actual outcome is a performance measure.

The studied approach to performance measurement as it relates to manufacturing began near the beginning of the twentieth century. Since the beginning of time men had been accomplishing tasks simply by starting them and continuing their efforts until the work was done. Certainly, estimates of the time and material required were made based on past experience, but there was no specific plan for adhering to them. The advent of the school of scientific management, led in this country by Frederic W. Taylor, brought to the attention of management the tremendous economies of developing <u>one</u> carefully planned method for accomplishing a task and adhering to it each time the job was repeated. It was also suggested that discrepancies between the planned results and the actual accomplishments be analyzed to determine the causes and that the variation be corrected. Taylor did not hesitate to encourage the replacement of one man with another whose physical characteristics enhanced performance - a practice that would seem somewhat discriminatory today. At the time of Taylor and his pioneering contemporaries, the labor content in a job was the prime target. Two distinct reasons accounted for this selection. Labor was the most significant cost factor in most cases, and the practice of "soldiering" made the inefficiencies of labor quite evident.

For the past 50 years manufacturing performance has been synonymous with direct labor efficiency. When Taylor began advocating the use of carefully determined standard times on jobs, there was little or no distinction between direct and indirect labor, work which adds value to the product and work which supports it. Each man did a job which contained elements of time which were sometimes direct and sometimes indirect. A standard was placed on his entire job and his performance (efficiency) was the ratio of standard time to actual time. Overall performance for the entire unit in which he worked was the standard time for total work produced divided by the actual time required. Other costs related to the manufacturing process were ignored. The error in this omission was not particularly serious since at that time the "other costs" were not significant by comparison.

As technology progressed, factors other than standard time rose in importance. Processes became more mechanized and the labor load shifted from that of producing parts to that of keeping the machines producing. Investments in physical plants skyrocketed and it became far more important to keep the equipment fully occupied than the men. Labor specialities such as maintenance, set-up, materials handling, and inspection developed to help keep the machines running. Because the production rates of the equipment rose higher and higher, the proportion of the labor force required as direct labor declined sharply. But, in spite of its diminishing importance as a cost factor, direct labor efficiency remained as the most common measure of departmental or plant performance.

It would be unfair to imply that the new factors which rose in importance were ignored. Almost every one of them has a standard, or even several, for evaluating its performance. It is precisely this fact which has created the problem in performance measurement that exists today. It is difficult, often impossible, to look at this array of measures and be able to state what the overall performance level is. This has left manufacturing enterprises in the position of not knowing how much room there is for improvement in their operations, or even if they are making any progress. For now, let this suffice as reason enough to seek a single measure. Later, use of that measure to accomplish this end will be expanded.

CHAPTER II

THE ENVIRONMENT OF THE PROBLEM UNDER STUDY

Before going any further, the following discussion will help to define the particular use of performance measurement under study and explain its role in management control.

Definitions

Many terms associated with performance measurement have acquired special meanings in each of several other areas. Because this study is limited to the manufacturing function it will help to give them specific meaning here.

(1) Manufacturing Unit - A manufacturing unit is that function which does the physical work in producing the product. Administrative, financial, and product and manufacturing engineering will be excluded. The boundaries will be such that the only variable factors included will be under the jurisdiction of the immediate supervisor of the unit. This definition necessarily limits the time span to the short-run. That is, a span such that physical facilities may not be altered.

(2) Performance - The accomplishment of a task or the operation of an activity usually according to a predetermined plan.

(3) Factors - Those items or activities which contribute significantly either for or against the achievement of the objectives of the manufacturing unit.

(4) Measurement - The assignment of a value to the performance of one of the factors.

(5) Standard - A value, at least temporarily fixed, which indicates the optimum performance under normal conditions. The performance measures should be constructed such that environmental conditions are normalized in order that the standard will represent optimum performance for that portion of the unit under consideration.

(6) Index - The result of the comparison of two measures of performance or of one measure and a standard for the performance of that activity.

The Value of Indices of Manufacturing Performance in Management Control

Because the index is the result of combining other terms, it seems appropriate to discuss at more length the forms that an index may take, some of the more common indices in use today, and their value to the manufacturing unit and the company as a whole.

Most frequently, an index takes the form of a ratio. For example, if the number of direct labor hours consumed in production (a performance measure) is divided by the number of units of product produced (another performance measure), the readily recognized index, hours/piece is formed:

$$\frac{\text{Direct Labor Hours}}{\text{Number of Pieces}} - \text{Hours per Piece}$$

A second generation index, direct labor efficiency, is obtained by dividing the hours/piece index into the standard hours/piece:

$$\frac{\text{Standard Hours per Piece}}{\text{Actual Hours per Piece}} = \text{Direct Labor Efficiency}$$

This is one of the most common indices used to measure manufacturing performance today. Others relate to materials usage, use of indirect labor and supplies, and scheduling. Each index either incorporates a standard value for the performance of the activity or may be compared to one. The value of the indices lies in the action taken as a result of this comparison. Each index is an integral part of a control feedback loop where a performance level that deviates significantly from the accepted level is detected and corrected. One need not be aware of the feedback loop approach to control to utilize it. The human body contains numerous examples of the loop which occur automatically, such as rapid breathing resulting from exercise and removal of the hand from a hot object. The human mind participates in thousands of such loops daily without being consciously aware of its role in the cycle. But, for this discussion, it is the planned use of the control loop that is of interest. Figure 1 shows the basic components of the feedback loop and indicates the role played by performance measurement and the index.

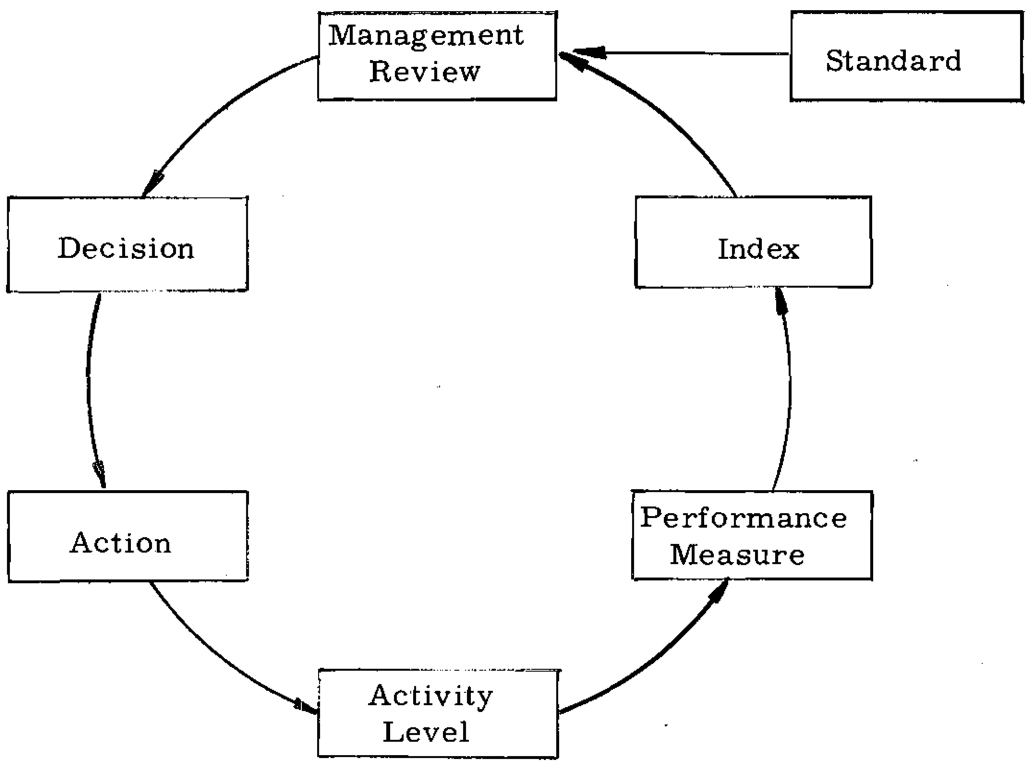


Figure 1 - The Role of Performance Measurement in Control

All control systems in use by manufacturing management employ the feedback loop principle, whether it is recognized as such or not. And, each of these loops incorporates the use of an index, whether calculated or not. Consider a simple example which the reader will surely be able to extend to encompass these systems and loops relevant to his own experiences.

A company is providing small stampings to a customer on a contract basis. The dies must be adjusted periodically to assure proper dimensions in the piece. History has shown that even when the dies are properly set, as many as 4 per cent of the parts may not meet the specifications. The price has been negotiated such that the customer will accept up to 5 per cent defects without rebate. Above that, full purchase price will be credited to him for all defective units. It is not economical for the supplier to inspect each part so he inspects on a sampling basis, checking 250 pieces each hour. He has found that if the per cent of defects exceeds 4 per cent for one hour, it will nearly always exceed 5 per cent for the next. So, he has decided that whenever the defect rate exceeds 4 per cent he will stop the process and adjust the dies.

Although such process controls exist in every enterprise, they are not commonly recognized as feedback loops. But, each portion of the loop may be easily identified here. The Activity Level is the rate at which defects are produced. The Performance Measure is the actual count of defective units. The Index is simply the number of defects divided by the sample size, 250. In this case, the Management Review and Decision occurred when the procedure was designed and are now automatic. That is, when the index exceeds 4 per cent the dies should be adjusted. The loop is not complete until the dies are reset; the Action must affect the Activity Level.

The simplicity of the index in this example tends to minimize its importance. But, it is simple only because the example is trivial when compared to the entire manufacturing unit. As will be shown later, the complexity of the index grows with the scope of the unit it measures.

Certainly, the importance of management control is self-evident and the existence of the feedback loop within the control system is easily seen. It follows, then, that the index, as a part of the loop, is a vital ingredient in insuring a successful operation.

CHAPTER III

USES OF THE SINGLE INDEX

As seen in the previous trivial example, an index relating to a particular aspect of an operation has a clearly defined use. One may conceive of many such indices. But, the argument of this thesis is that a single value combining all of the other indices will be beneficial to manufacturing management. Following are some reasons why such a value would be of use.

The Single Index Alone

Assuming that proper formulation of the index can compensate for the differences in the factors which contribute to the performance of various manufacturing units, indices for several units may be compared directly with one another. A small unit may be compared with a large one. Even a portion of a unit may be compared with its whole; a foreman with his superintendent. That is not to say that if the indices are the same that the foreman could have done the superintendent's job, but that they did equally well at managing their respective units.

Because the index should be constructed to be indifferent to the change of environmental forces, valid comparisons can be made with the performance of other time periods - or with an anticipated or an aspirational index value.

In summary, the single index will eliminate the need to, and the opportunity for, enumerating the circumstances which lie behind a particular index value. It will permit a manager to make a quick survey of those units under his jurisdiction, select those meriting his attention, and then delve into the details which cause an index to behave as it does.

The Factors Comprising the Single Index

The formulation of the index will necessarily define the relationships between factors within the unit and the contribution of each factor to the total measure. Both the operating and planning functions of the enterprise may make use of this concept.

(1) Operating - When the total-unit index behaves so as to raise suspicion about the performance of the unit, management may step down to the next level of detail and examine the factors which comprise the index. Should the change in the general index be sudden, it is likely that its movement is a reflection of an abrubt change in one or more of the factors in the formulation. They may be quickly singled out for management attention.

It is the author's conjecture that the converse does not necessarily hold. That is, that sudden changes in the factors do not always force a similar shift in the general index. Often a sudden change in one factor will be offset by a change in the opposite direction of another. Should a unit supervisor be having difficulty with one activity, he may counteract it with above level performance from another. Or, it is possible that a higher cost in one area promotes a lower cost in another. For example, slowing down direct labor may enhance quality. The fact that this type of interaction may keep the overall measure level permits the unit supervisor to have a great deal more flexibility. Management will not criticize him unduly the instant one of the factors fluctuates more than normally expected. It gives him a chance to work out his own problems without uninvited pressure and also to experiment in shifting the balance among the activities.

(2) Planning - Because the interrelationships and contributions of factors are explicitly defined in the formulation of the general index, the effects of changing the emphasis on the various activities may be studied in advance. Different combinations of activity performance may be plugged into the formulation in an attempt to discover an optimum, or more practically, just an improvement over existing ones. It may be found that a small improvement in one activity will yield a large improvement in the overall index. Or, it may be that a big change in the performance of one activity will show less change in the total than expected.

For given expected performance of individual activities new relationships between them could be sought and then implemented in the real unit should they indicate a better overall performance. Perhaps if direct labor were less dependent upon indirect labor (i. e., set-up, maintenance, materials handling, etc.) the general index would rise, even should direct labor suffer a small shift in its own performance from undertaking some indirect functions.

Characteristics of the Single Index

In order that a single valued index which represents the performance of the entire manufacturing unit may fulfill the uses outlined above, it must have certain characteristics.

(1) Free of external influence - The index must be a factor of only those activities within the control of the manufacturing unit. Since it is the aggregate performance of these internal activities that is being sought, the effect of external factors must be removed, not ignored.

(2) Repeatable - The procedure for calculating the index must be such that a similar computation can be made repeatedly over a period of time.

(3) Universal - The same philosophy and procedure must apply over a myriad of manufacturing units and operating situations.

(4) Diagnostic - The development of the single index should point clearly to those activities which are creating significant changes in the overall value. It should be possible to rank the activities in an order which will permit corrective effort to be utilized most effectively.

(5) Understandable - The resulting index must have importance because those using it understand how it was developed, and not because of management emphasis.

(6) Economical - The index must not cost more to develop, maintain and modify than it is worth as a control tool. This consideration may be helpful in determining the detail level of the index.

CHAPTER IV

CURRENT METHODS IN DEVELOPING INDICES

Assuming that the use of indices is imperative, one of the problems associated with their use is pointed out by Richards and Greenlaw: "In any organizational system or sub-system of any magnitude, the use of literally thousands of performance measures might be conceivable." (1). The rest of the major problems all stem from this initial one. The cost of measuring and controlling all of the variables in a manufacturing unit, regardless of how small, would be extremely prohibitive. It is fortunate that many of the variables are dependent upon others and their control follows with the control of the associated independent variable. Even so, the number of independent factors remaining is still too large for each to be considered separately. If a cost effect could be attributed solely to each factor, then on the basis of simple economics, one could select those for which the cost of control is less than the benefits of control. Assuming that the number of factors is now manageable and economical, the problem of obtaining from them some measure of overall effectiveness still remains. Three methods of arriving at this overall measure are in use today.

Individual Indices

One may assume that one factor is extremely dominant and use its index of performance as the index for the manufacturing unit. Because, at one time in the history of manufacturing, labor was such a dominant factor in production costs, the direct labor efficiency index was accepted as the performance index for the entire plant. Today, even though in many instances the per cent of direct labor cost to total cost is only a fraction of what it once was, this index has remained as _the_ indication of plant efficiency.

The fallacy of this approach is in its application. That is, assuming that direct labor is very dominant when, in fact, it may be relatively insignificant. Often, direct labor is a dependent factor; dependent upon a factor outside the jurisdiction of the supervisor of the unit under study. The injustice of evaluating his performance by a factor under someone elses control is obvious.

Another problem associated with using the indices independently is that of sub-optimization. If the man responsible for a given activity is attempting to improve his index, he might well be performing such that he reduces the index of other activities. It is a well known fact that in a system with interdependent variables, one can seldom optimize the performance of the system by optimizing each component individually. Even if this fact is recognized, it means that each index must be evaluated with respect to the others.

Although it may be feasible to decide that the value of any particular index is good or bad, it would be most difficult to draw any conclusions about the system as a whole.

Combinations of Indices

Many attempts have been made to combine factors into a single value to represent the performance of the entire unit. Because the argument of this thesis is that the single value index is a useful tool, the discussion at this point will be limited to the shortcomings of current attempts at combination.

As nearly as may be told from an extensive literature search, almost all indices designed to measure overall performance by including all of the significant factors have been limited to simple summations of individual indices or, at best, weighted summations of them. Although the weighted method goes a long way to overcome the differences in contribution to overall performance by each factor, it does not cope with the interrelationships of factors. It is true that in some situations this consideration may be negligible, but it is doubtful that such is the case in a manufacturing unit of any size. As the number of factors grow, the number of interrelationships grow at an even faster rate. To try to include all of these would be foolhardy. To ignore all of them would be equally so.

A method described by Bela Gold from the University of Pittsburgh which begins with desired overall index and then partitions it into components seems to be headed in the right direction (2). However, his examples included more than the manufacturing unit. This approach will be discussed further under the development of the single index.

Combinations of Leading Indices

Borrowing some of the simplicity from the dominant factor assumption and some of the sophistication from the combination approach, this concept has found good application where the number of leading indices are few and their interrelationships are clear.

A good example is a system used by a large manufacturer which calculates an index as follows:

$$\text{Index} = \text{Direct Labor Efficiency} \times \text{Utilization Ratio}$$

Here an employee records his time as either on a standardized job or an off-standard job. The utilization ratio is the time recorded on standardized jobs divided by the total time recorded. The direct labor efficiency is the normal calculation of actual output divided by output expected for the hours spent on standardized jobs.

This index proves useful in those instances where a very high per cent of the activity is standardized and under the control of the unit supervisor. It is impossible, however, to draw direct comparisons between manufacturing units when the per cent of work standardized or when the ease of remaining on a standardized job differs. It will be seen later that this formulation will conform to the guides for developing indices when direct labor is an extremely dominant factor and is independent of external influences.

CHAPTER V

PROBLEMS ASSOCIATED WITH DEVELOPING A SINGLE INDEX

It is difficult to say just what problems can be associated with a single index for manufacturing performance because their use is either non-existent, secretive, or so limited that little material has ever been published. In all of the literature surveyed, not once did the author uncover so much as a mention of a single overall index of manufacturing performance alone. As mentioned previously, a great deal has been done on evaluating the effectiveness of the entire enterprise. This measure normally results in an expression of return on investment or a summation of ratings of various functions (3, 4). It would appear, then, that the paramount problem at this time is one of salesmanship. If there is value in the single index concept, then both the industrial and academic spheres must be convinced so that effort may be expended for its continued development.

Once acceptance is gained, three sets of problems may be anticipated: those related to planning, operating, and updating.

Planning

The problems encountered in planning will be those of defining the scope of the unit to be measured, enumerating the factors which contribute to performance, both positive and negative, and establishing the interrelationship between these factors.

Of course, the scope of the unit will be totally dependent upon the type and level of operation. As stated earlier, the unit may be a large manufacturing complex with capital equipment in the hundreds of millions of dollars and employment in thousands of workers, or it may just as well be a small department with little or no equipment and a dozen or so people. As would be expected, as the size of the unit increases, the number of significant factors contributing to performance will rise also. It is not, however, the number of factors used that makes a performance measure a good one or a bad one, but whether or not all significant factors are included. The important criterion to remember in defining scope is to get far enough away from the object of study to see all of those factors which affect it.

The interrelationship of factors, both inside and outside the unit, is perhaps the biggest stumbling block in developing a single valued measure. The fact that the factors do interact is easily recognizable, but difficulty in placing a quantitative value on the relationship seems to have stopped all efforts in this direction.

The contribution of individual factors to the total performance level has nearly equalled the interrelationship problem in difficulty, but more significant advances have been made in this area. Most techniques depend on the additivity of factors and then weigh each factor according to its importance.

Both current and proposed attempts to cope with these problems will be covered in greater detail in a later section of the thesis.

Operating

Under the assumption that a meaningful single index can be developed, it is not difficult to imagine some of the problems associated with making it useful as a management control tool. The amount of data required and the frequency of collection would probably have been prohibitive as few as five to ten years ago, but today there are available, and in extensive use, vast systems for the collection, consolidation, analysis, storage, and reporting of data. Most frequently known as management information systems, this concept has already enabled management to make more effective decisions which include many times the number of factors which could have been considered previously. The current rate of progress in linking remote input-output terminals with a central electronic data processing unit should permit nearly constant auditing of almost every variable in the manufacturing system.

With the exception of acceptance by personnel, a problem encountered in establishing any new procedure, the problems of operating a single valued measurement system have been overcome to a large extent. Continued progress in providing the mechanics required will certainly outstrip that in developing comprehensive performance indices.

Updating

In a measurement system designed to take into account the effect of as many factors affecting performance as possible, it is evident that changes in the formulation of indices will be necessitated by the nearly constantly changing environment. The system must then be designed such that factors are not imbedded so deeply in a formulation that their effect may not be varied. If changes in the manufacturing unit and its environment cannot be reflected quickly in the performance measures, the measures will lose their value as a control tool. Beyond the problem of recognizing changes in the physical system and being willing to modify the measures accordingly, the updating problem must be solved in the planning, or formulation, stage.

CHAPTER VI

A SOLUTION APPROACH

The problem of formulation falls into three main categories:

(1) Selecting factors which are significant.

(2) Establishing the relationship between them.

(3) Determining how each one contributes to the overall performance.

A considerable amount of work has been done in the first area. Few authors writing on the subject of plant management or management control fail to include a listing of factors whose costs need to be measured and controlled. Nearly all of the work, however, is repetitive since it is not an area subject to startling discoveries. Within the past ten years some advances have been made in the third area; notably, the duPont approach of breaking the return-on-investment ratio into its more detailed component ratios (see Figure 2), a method for weighting factors included in Introduction to Operations Research by Churchman, Ackoff, and Arnoff (5), and the system used by Martindell in his performance appraisals. The problem of establishing the relationship between factors stands as the one most

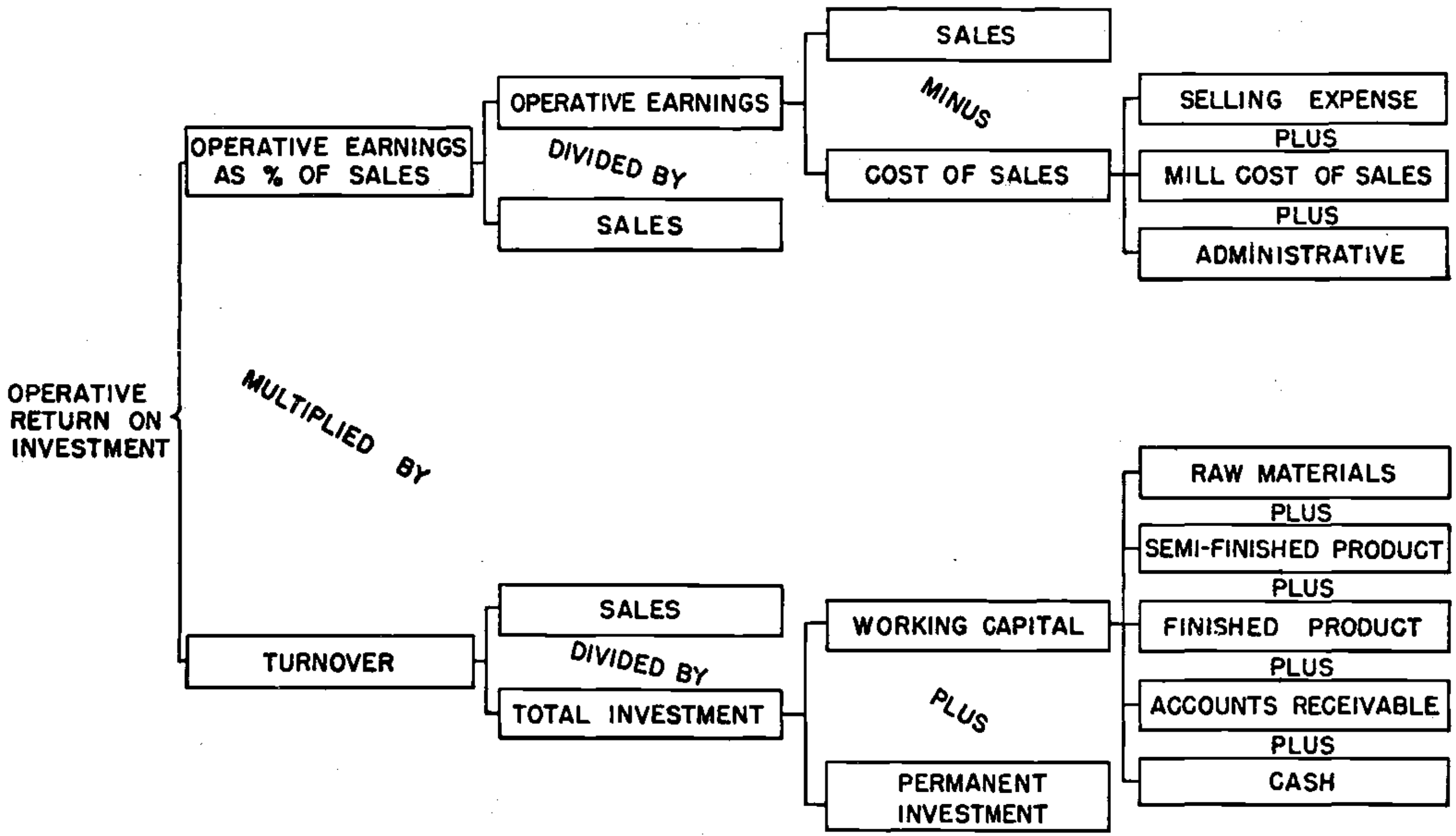


Figure 2 - duPont Return on Investment Calculation

(after Amrine, Ritchie, and Hulley, Manufacturing Organization and Management, Second Edition) needing further development. The literature reveals only the slightest mention that there is even a possibility that the factors may effect one another, and not even a hint as to how such an interaction may be accounted for.

The weighted summation of individual performance factors is the most easily used and most quickly understood method of combining all activities into a single performance value for the entire unit. It also has the advantage of revealing immediately the factor or factors which are instrumental in making the overall value high or low. Regardless of weight, any factor which has a performance value below the overall is pulling it down. The drawback of the summation is that it does not reflect the interaction between activities. If one activity has a great influence on the performance of another, the dependent activity will share the responsibility for the low performance level of the independent one. Because interaction does exist between activities in a manufacturing unit, the advantages of current techniques of weighted summation are all but nullified.

The concept underlying this thesis is that if the factors representing the performance of each activity can be adjusted so as to be independent, then the weighted summation method of combination will be valid. The proposed approach will utilize an information feedback concept of activity interaction to develop the adjusted performance factors in conjunction with a method for weighting factors which considers the fact that some activities have a strong influence in controlling the performance, and hence the cost, of others. Each of the three problem categories will be explored in turn, beginning with the selection of activities.

The Selection of Individual Activities

It would be impossible to list here all of the activities which have a bearing on overall manufacturing unit performance since those present in a particular situation are dictated by the industry, size of facility, the extent of mechanization and many other factors. Rather, general criteria for the selection of activities will be discussed and a number of the more generally significant ones will be enumerated and defined.

Distinguishing Activities

Because many of the variables associated with the manufacturing unit will not qualify as activities, as the term is employed in this thesis, it is necessary to distinguish the activities from the other factors. Since all of the items appearing in a manufacturing budget contribute to the total cost of operation, each will be considered as a "cost factor." Those factors which may be thought of as having a measurable performance level will be considered as "activities" and the remainder designated as "pure cost factors." In general, the activities will be identifiable by the fact that their costs are those which are incurred in the performance of a task.

Criteria for Selecting Activities

As indicated earlier, the significance of activities will change with time. Not long ago only direct labor was considered worth worrying about. The reason is obvious - and valid. This was the extent to which costs were broken down. Now, with elaborate information and accounting systems keeping constant tabs on production data, there is no excuse for being content with using the performance of only one activity to measure overall manufacturing unit performance (as many still seem to be). The most general criterion for selecting activities to include would be to select those which either make a significant contribution to production costs or which have an affect upon other factors which do. This rule will, then, force the inclusion of external as well as internal activities. As a simple example, purchasing makes no direct contribution to costs in the manufacturing unit, but it does a great deal to affect such items as scrap rate which does. Because this criterion permits much latitude in selecting activities, based on the desired level of detail and accuracy, it is the one which will be included in the system proposed here.

One might assume that if he can control a given per cent of the costs, that he has sufficient control of the entire unit; that is, with normal effort, the other costs will fall in line. If such an assumption is made, beginning with the largest single cost factor and working downward, the least number of activities controlling that per cent of the cost may be obtained. It should suffice to say that it is desirable, from the standpoint of efficiency, to use the least number of activities which satisfies the required level of control.

A procedure that may be used would be to rank all of the cost factors on a manufacturing budget in descending order of cost. Select a desired level of control, say 95 per cent, and beginning with the largest cost factor, work down the list until 95 per cent of the total cost has been included. For each factor list those others, in addition to its own self-control, which have an effect in controlling its cost. It will be noticed that now some factors which are external to the manufacturing unit and also some which are internal but were not included in the original list will be added. Now, a complete list of the factors controlling at least 95 per cent of the total unit cost has been developed. From this list, select those factors which fit the description of activities. Figure 3 indicates the selection of activities from a typical budget for a small sheet metal enterprise employing about forty people.

Defining Activities

Without careful definition of the activities, it will be difficult to understand and to formulate the adjusted indices. Unless the precise boundaries of the activities are known, it is difficult to tell which other ones affect it and which do not - and to assess the magnitude of that affect.

Item	Monthly Budgeted Dollars	Rank	Sel. as A Prime Factor	Controlling Factors	Selection as an Activity
Direct Labor	$10,000	1	✓	Direct Labor	✓
				Materials Handling	✓
				Clerical & Dispatching	✓
				Supervision	✓
				Set-up	✓
Overtime Premiums	3,200	2	✓	Overtime Premium	Not an activity
				Scheduling (external)	
				Set-up	Already included
				Direct Labor	"
				Clerical & Dispatching	"
Set-up	1,500	4	✓	Set-up	"
				Supervision	"
				Clerical & Dispatching	"
Supervision	1,600	3	✓	Scheduling (external)	"
Clerical & Dispatching	550	8			
Materials Handling	800	6	✓	Materials Handling	Already included
				Supervision	"
Inspection	1,100	5	✓	Inspection	✓
				Scrap	Not an activity
Scrap	300	11			
Rework	800	6	✓	Rework	✓
				Scrap	Not an activity
Maintenance & Repair	500	9			
Shop Supplies	350	10			
Utilities	100	13			
Non-Durable Tools	250	12			
	$21,050				

Figure 3 - Manufacturing Budget

For clarity, consider the following definitions of some of the most common activities in a manufacturing unit. These do not represent all of the significant activities, but enough to illustrate the extent to which they must be defined. For the purposes of illustration, from here to the end of the thesis, the manufacturing unit under consideration as an example will be the small sheet metal stamping enterprise. It has been selected because it more readily exhibits the effect of activities upon one another and upon the overall performance than most other processes. It is interesting to contemplate the changes that would be required in the definitions should a different type of activity be under consideration.

Direct Labor will refer to that time or cost required to transform the piece from one stage of completion to the next as called for in the normal process. Direct Labor will not include handling of the parts except into and out of the machine, nor will it include the rework of defective pieces.

Set-up is the time or cost devoted to preparing a machine or workplace for production, including tryout production. This definition assumes that the process will not be altered once set-up is accomplished, that the production rate will be the same for the duration of the lot run, and that it will be dependent upon the quality of the set-up job. Notice that the learning curve often observed in stamping operations has been placed in the set-up time rather than in production time.

Maintenance and Repair is the effort expended for both routine and emergency maintenance of facilities. It is that activity which keeps the machinery in working order and, hence, is a direct contributor to the production rate.

Determining Activity Interaction

To facilitate development of this portion of the approach, two reasonable assumptions may be made:

(i) Standards have been set and sufficient data is available to develop measures of performance of the individual activities. These measures are functions of effort and output only. They are available for use. Although few companies have standards set on all of the significant activities within their manufacturing system, it may be safely assumed that with good reason and sufficient effort they could be developed.

(ii) The effect that one activity has on another is a function if its raw measure rather than of the adjusted measure that is being sought. That is, the effect is a function of the output of the activity and not the job that was accomplished within the activity. If an activity has poor input, it may have great internal efficiency which will not be reflected in its output. And, it is the output which affects succeeding activities.

Recognizing Activity Interaction

Perhaps the surest way to recognize activity interaction is to listen to excuses offered by the supervisors explaining why they were not to blame for a low performance reading. These excuses will assist in beginning a list of contributing factors. It is unlikely that any activities which have a constructive affect on the activity will be included. A foreman would not be inclined to volunteer that he did not lose a single piece due to the good quality of incoming material, but rather be happy to be able to enhance his own efficiency with such a stroke of good fortune. It should be evident, however, that any activity which makes a negative contribution is doing so because of its own performance, and should this performance rise it would make a more positive contribution. The converse holds, also; activities which are making a positive contribution now may reverse themselves in the future.

Although this task seems imposing, it may be simplified by using the same criterion used in selecting the major factors. That is, stop searching when it appears that all of those activities that make a significant contribution have been found. Notice that activities not previously listed will now arise. Many will be external to the manufacturing unit, and some will be internal activities not previously considered to have sufficient affect on the overall performance level in their own right.

A good method for visualizing activity interaction is to draw a flow diagram. Let each activity be represented by a labeled rectangle. Draw directed lines between them, indicating the effect of one on another. With all of the activities spread on the diagram, it is probable that forgotten relationships will be recalled. Figure 4 shows a portion of the flow diagram for the sheet metal unit under consideration.

Determining the Magnitude of Interaction

The current state of the art of performance measurement requires that placing a quantitative value on the effect of one activity on another be the result of an educated guess. In addition to the fact that activities affect each other, it must also be recognized that each has some proportion of self-control.

If it is assumed that each affecting activity has an independent effect on the activity under consideration, then a two coordinate plot can be made which displays the reaction of one activity to changes in the other. Figure 5 shows how Direct Labor performance will fluctuate when the performance of Set-up changes.

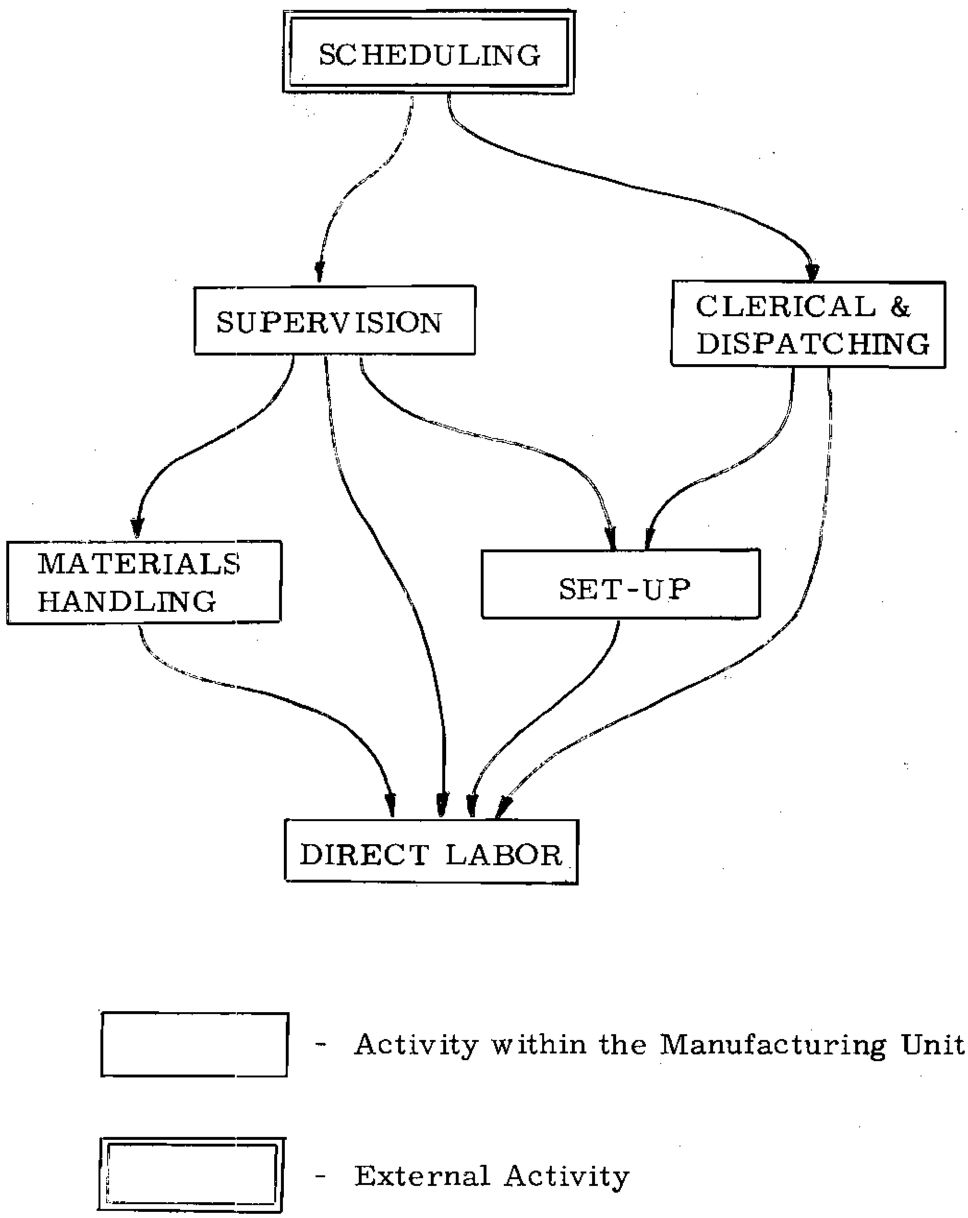


Figure 4 - Flow Diagram for Direct Labor Performance Control

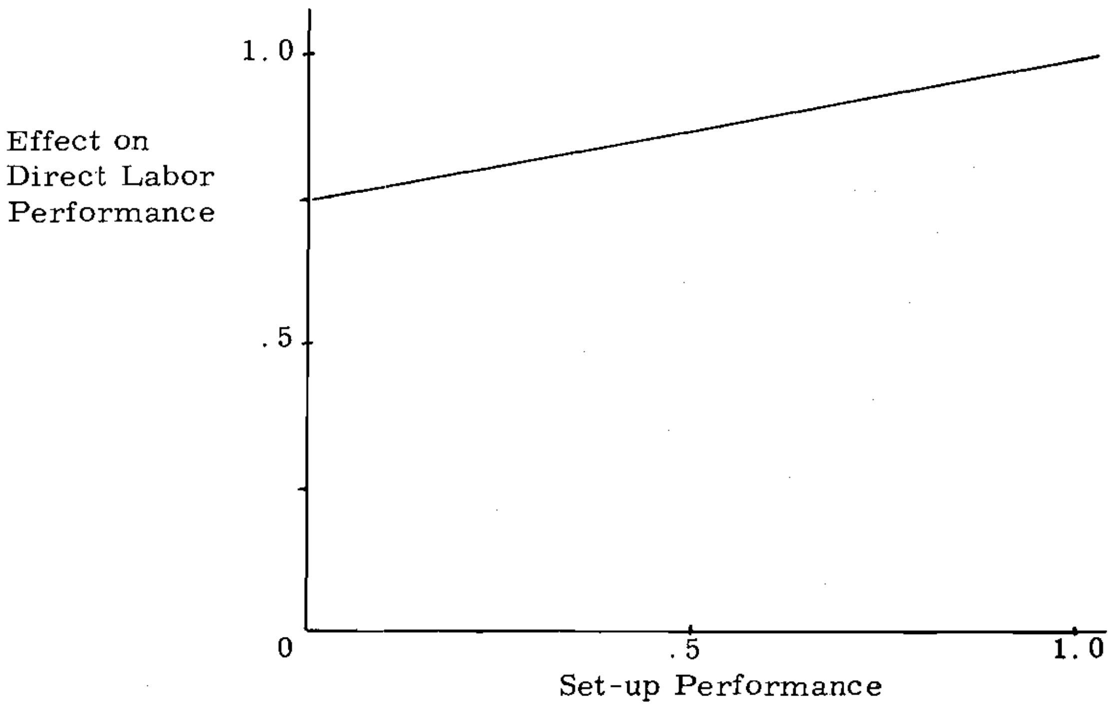


Figure 5 - Direct Labor and Set-up Relationship

In effect, this graph says that Set-up will never lower Direct Labor by more than 25 per cent - even if its own performance goes to zero. It should be noted that the significant portion of this graph is in the upper region (say above 50 per cent) which represents the normal operating range.

Unless a great deal of effort has been put into running controlled experiments and the collection of data, this relationship is, at best, a guess. There have been many arguments cited against the use of relatively unfounded values, but in the absence of factual knowledge it is better to make an estimate than to omit consideration of the relationship. As Forester pointed out in developing his industrial dynamics models: "To omit a factor is to assume that its effect is zero - probably the one value that we know is not true." (6).

Because these relationships between activities are only estimates, for the development of a general model, a linear relationship in the significant region will be considered. Later, some discussion will be devoted to the development of non-linear relationships.

Formulating the Adjusted Performance

With the relationship between activities established in graphical form, the task of converting the plot to a more convenient form remains. Consider the trivial case in which only one other activity affects the one being adjusted. The following equation will hold:

$$\left(\begin{array}{l}\text{True performance of}\\ \text{activity under consideration}\end{array}\right)\left(\begin{array}{l}\text{effect of the}\\ \text{other activity}\end{array}\right) = \left(\begin{array}{l}\text{measured or}\\ \text{raw performance}\\ \text{of activity under}\\ \text{consideration}\end{array}\right)$$

Since the measured performance is known and the true or adjusted performance is being sought, dividing both sides by the effect of the independent activity will yield a solution. The following expression is an algebraic representation of the graph in Figure 5:

$$\left[1 - .25\ (1 - \text{Set-up Performance})\right]$$

Both the raw performance of the activity under consideration and that of the affecting activity have been assumed measurable. The following example shows the computation of an adjusted Direct Labor performance when Set-up is the only other activity affecting it.

Let - Measured Direct Labor Performance (DL) = .80

- Measured Set-up Performance (SU) = .90

Then using the relationship in Figure 5, the Adjusted Direct Labor Performance (DL adj.) may be computed:

$$DLadj = \frac{DL}{[1-.25(1-SU)]}$$

$$DLadj = \frac{.80}{[1-.25\,(1-.90)]}$$

$$DLadj = .8215$$

The adjusted Direct Labor performance is higher than the measured value because now the adverse effects of a Set-up performance, which is below standard, have been removed. If it is assumed that each affecting activity has an independent effect on the activity being adjusted, then the new value may be obtained by a succession of divisions by terms which include the appropriate effect and performance for each affecting activity. Continuing the direct labor example, consider the relationships shown in Figure 6.

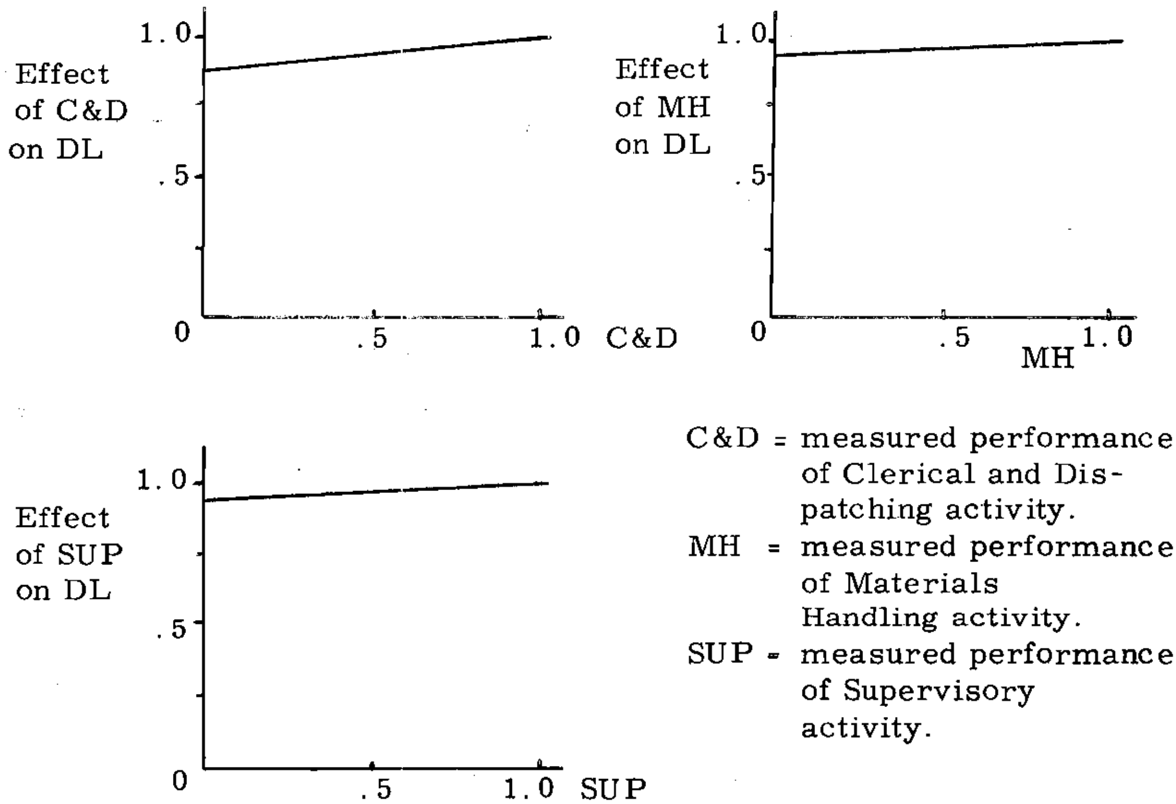


Figure 6 - Other Direct Labor Relationships

Let C&D = .75

MH = .75

SUP = .95

The formulation for the adjusted Direct Labor performance would then be:

$$DLadj = .80\left[\frac{1}{1-.25(1-.90)}\right]\left[\frac{1}{1-.125(1-.75)}\right]\left[\frac{1}{1-.0625(1-.75)}\right]\left[\frac{1}{1-.0625(1-.95)}\right]$$

$$DLadj = .80\left[\frac{1}{.975}\right]\left[\frac{1}{.96875}\right]\left[\frac{1}{.984375}\right]\left[\frac{1}{.996875}\right]$$

$$DLadj = .865$$

The extension to the general model for the case of independent linear effects is now accomplished with ease:

Let X_i = the measured performance of the activity i
$i = 1, 2, .. n$

X_m = the activity whose adjusted performance is being computed

$W_{i,m}$ = the maximum effect of activity i on activity m

Y_m = the adjusted performance of activity M

then -

$$Y_m = X_m \left[\frac{1}{1-W_{1,m}(1-X_1)}\right]\left[\frac{1}{1-W_{2,m}(1-X_2)}\right] \cdots\cdots$$

$$\cdots\cdots \left[\frac{1}{1-W_{m-1,m}(1-X_{m-1})}\right]\left[\frac{1}{1-W_{m+1,m}(1-X_{m+1})}\right] \cdots$$

$$\cdots\cdots \left[\frac{1}{1-W_{n,m}(1-X_n)}\right]$$

The handling of non-linear relationships between activities requires only a modification of the denominator in each factor. For simplicity, a linear relationship between activities was assumed. An expression for any other relationship might have been included. However, it is often difficult to find a convenient mathematical representation for the way that one activity affects another. Recall that the expression used in the denominator was merely a representation of a graphical relationship, and that it would have been equally appropriate to consult the graph for a value. In that case, the relationship could just as easily have been non-linear.

Since this type of calculation would probably be assigned to a computer, the cumbersome operation of referring to a book of tables is not a determining factor in selecting the type of relationship to use. The computer can accomplish this task as easily as calculating the expression. In normal computer operations, a curve may be represented by a series of connected straight lines for which only the end points need to be provided as data, and often only the increment of the independent variable and the value of the independent variable. Figure 7 shows a relationship between Direct Labor and Set-up in which extremely low values of Set-up performance have severe effects on Direct Labor. Even large changes in the intermediate range have almost no effect, and small increases at high performance levels do much to assist Direct Labor.

The use of tables permits virtually any relationship between activities to be included in the formulation. The tables, combined with computer capability help to make this approach far more general.

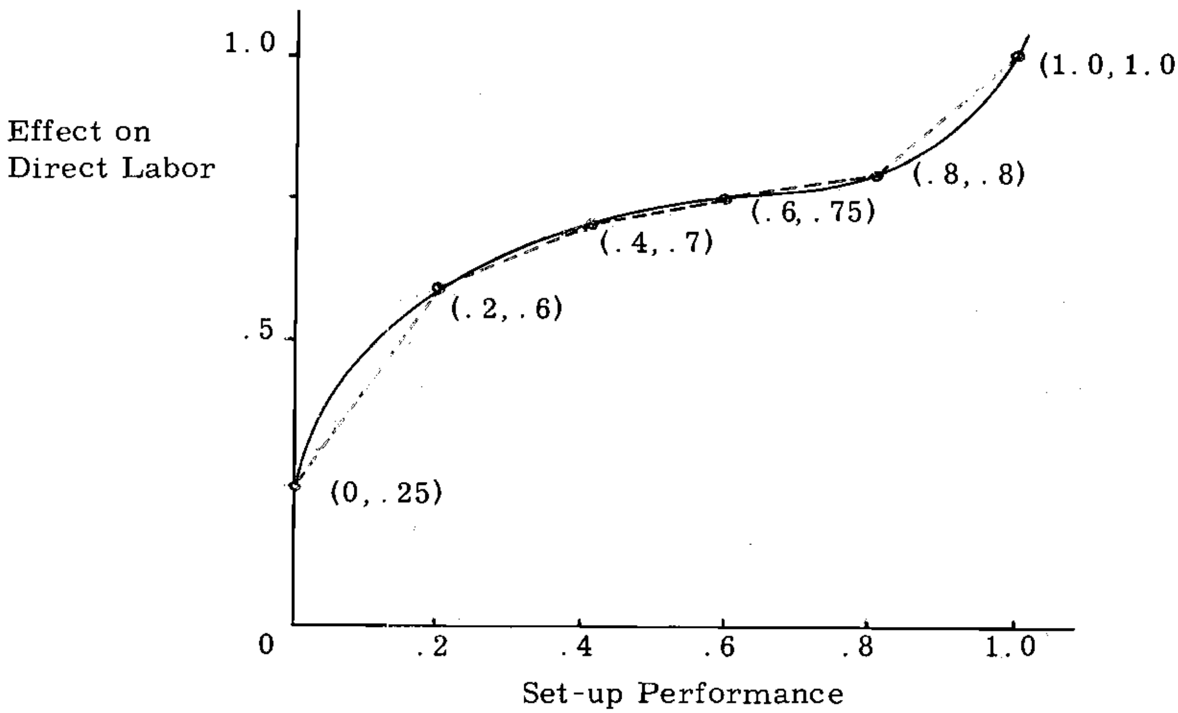


Figure 7 - A Non-linear Relationship

Combining Factor Indices

The final step in developing a measure of the overall performance of the manufacturing unit is to combine the activity performance measures in such a way as to indicate the effect of each activity on the whole organization. The approach proposed here is a weighted summation of the adjusted performance levels of each of the activities. The concept is one of forcing each activity to carry the responsibility not for the costs that it incurs, but for the costs that it controls. It will be recalled that in determining activity relationships, the extent to which one controlled another was established - and that effect varies with the performance level of the independent activity. The closer that the performance of the affecting activity is to standard, the more control the activity under consideration has over its own costs.

Determining Control of Cost Factors

The flow diagram, of which a portion was shown in Figure 4, may be extended to include the pure cost factors which were part of the initial list selected from the budget. Once again, arrows may be drawn to indicate the dependence of one factor upon the performance of another. Figure 8 is the same portion as shown in Figure 4, but with the additional relevant factors added. Linear relationships similar to those shown in Figure 5 and 6 or non-linear relationships as in Figure 7 may be established. A high degree of the control of many of the cost factors may be attributed to activities outside the manufacturing unit. These must be included in order to properly determine the effect of internal activities.

When a cost factor has a controlling influence on another factor or on an activity, its relationship will be fixed, since no variable performance level is associated with a pure cost factor. In determining the cost controlling relationships, it will be found that since control varies with the performance of the controlling activities that one of these must be equal to the difference between total

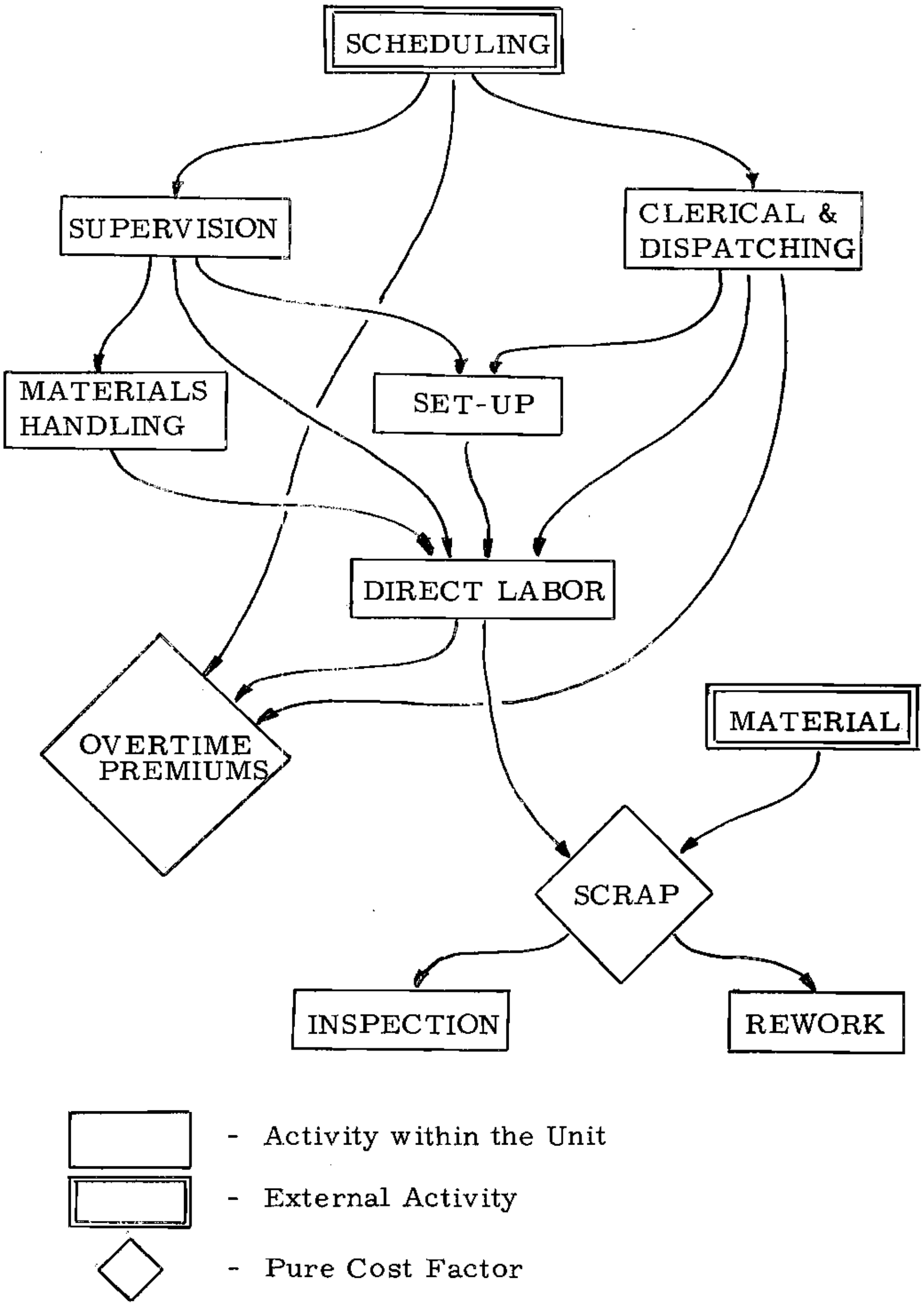
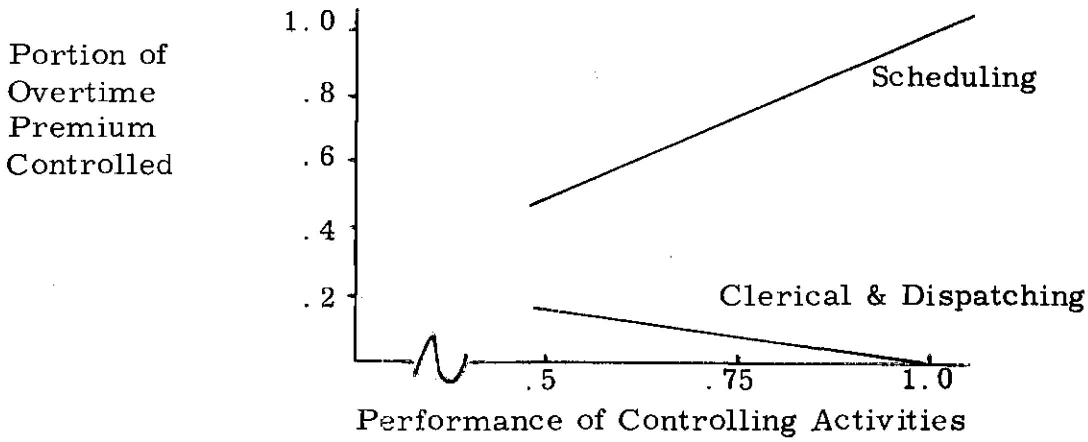


Figure 8 - Flow Diagram for the Manufacturing Unit Cost Control

control and that portion controlled by the remaining activities. When it is an activity whose cost control is being determined, it is most convenient to assume that its own self-control is the one which accepts the slack. When a pure cost factor is being evaluated, it cannot control any of its own costs; hence, this slack role must be assigned to another activity. A sampling of relationships indicated in the flow diagram is shown in Figure 9.

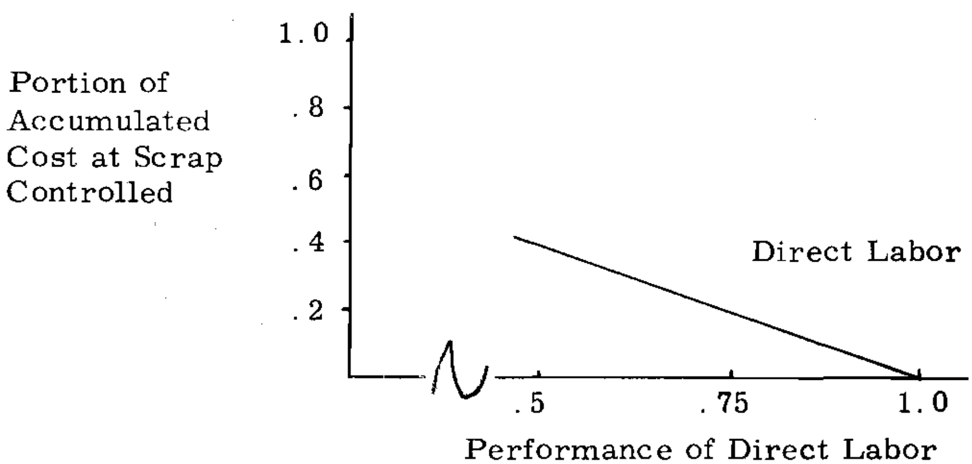
Weighting the Activities and Determining Overall Performance

A problem which arises from the use of the relationships previously developed is that an activity which controls a significant portion of a cost factor may itself be controlled by another activity. The performance of some activities will have a cascading effect on many others which occur after it in the manufacturing process. For example, Direct Labor performance will have an effect upon the amount of overtime required to meet the production schedule. But, since Direct Labor is partially dependent upon several other activities, then, these too, must have at least an indirect effect on overtime. Some activities may have both a direct and an indirect effect on a cost factor. The problem, then, is that the cost that an activity controls cannot be calculated until the controlled costs of all of the activities and factors dependent upon it have been determined.



Direct Labor controls the remainder.

Scrap controls: 25 per cent of Inspection costs.
80 per cent of Rework costs.



Material controls the remainder.

Figure 9 - Control Relationships

To begin the procedure, record the value of the actual cost incurred for those factors which have no controlling effect on any others. In Figure 8 Overtime Premiums, Inspection, and Rework are examples of these factors. To calculate the cost controlled by the next level, say the Scrap factor, those portions of Inspection and Rework which are controlled by Scrap should be added to the actual incurred cost of Scrap and the total recorded. Also, those Inspection and Rework costs controlled by Scrap should be subtracted from the cost of these activities.

From the relationship in Figure 9 the accumulated controlled cost at the scrap factor may be calculated as follows:

Let Inspection Cost = \$1100

Rework Cost = \$ 800

Scrap Cost = \$ 300

Controlled Cost = Scrap Cost

- Scrap Control of Rework Cost (Rework Cost)

- Scrap Control of Inspection Cost (Insp. Cost)

= 300 - .8 (800) - .25 (1100)

= \$1215

Of course, since Scrap is a pure cost factor, all of this cost will be assigned to those activities which determine the extent of Scrap.

The backtracking procedure may be followed up through the flow diagram until a value for each activity has been obtained. The value associated with each activity or factor does not represent the cost which it controls, because it still includes that portion controlled by preceding activities. These costs must be subtracted. The remainder now represents the total costs assigned to each activity. Although there was an accumulated controlled cost at each of the factors, the costs actually controlled by any pure cost factor will become zero since 100 percent of its cost is controlled by some activity or activities and, hence, will be subtracted out.

If the costs assigned to each activity are added, the total will fall short of the total manufacturing costs for two reasons: (1) some cost factors were ignored as being insignificant, and (2) the control of a high percentage of manufacturing costs lies outside the manufacturing function. The total will represent the significant costs controlled by the performance of activities within the function. The total controlled costs divided by total incurred costs may be considered as a measure of the autonomy of the manufacturing unit.

Since the aggregate of the activity performances is the object of this research, the weight carried by each activity's adjusted performance will be equal to the cost that it controls divided by the total cost controlled from within the manufacturing unit. The overall performance measure of the manufacturing unit will be the sum of the adjusted and weighted performances of the activities within the unit.

Figure 10 is a table designed to summarize the values calculated for each activity. Calculations for the adjusted performance and weight of activities not included in the text may be found in the appendix. The value in the lower right-hand corner of the table is the measure of overall performance. This measure represents the aggregate performance of those activities which are controlled within the framework of the manufacturing unit. If this value is high, and the facility output seems unreasonably low, then one should look to external activities for a solution, not to the manufacturing function. On the other hand, if this value is low and output is still at normal levels, then one can assume that the manufacturing function is not utilizing an exceptionally good combination of inputs to best advantage.

Within the unit itself, it is possible to quickly pinpoint those activities in need of attention. The weight of an activity is equal to its contribution to the total when its adjusted performance is 100 per cent. Consequently, the difference between an activity's contribution to the total and its weight is exactly the amount by which it is raising or lowering the overall performance from 100 per cent. Large differences indicate need for immediate action. If negative, the action is one of correction. If positive, it is one of encouragement.

TABULATION OF PERFORMANCE VALUES AND WEIGHTS

Activity	Measured Performance	Adjusted Performance	Incurred Cost	Controlled Cost	Weight	Contributions to Total
SUPERVISION	.95	1.011	$ 1600.	$ 1820.	.100	.101
CLERICAL & DISP.	.75	.833	550.	1234.	.069	.057
MAT. HAND.	.75	.154	800.	1157.	.064	.048
SET-UP	.90	1.039	1500.	1848	.101	.105
DIRECT LABOR	.80	.865	10,000.	11,166.	.612	.529
INSPECTION	.70	.700	1,100	825	.045	.032
REWORK	.65	.650	800.	160	.009	.006
TOTALS (where applicable)			$ 16,350.	$ 18,210.	1.0	.878

Figure 10 - Tabulation of Calculations

CHAPTER VII

CONCLUSION AND RECOMMENDATIONS

It is evident from the lack of material available that measuring the performance of the manufacturing unit has been all but neglected. It is difficult to conjecture why this is so, because it is apparent, at least to this author, that such a measure can do a great deal to assist in improving overall manufacturing performance. As a matter of fact, the mere pursuit of such a measure is likely to bring sufficient emphasis on the problems associated with the operation of the unit to contribute to a better understanding of the requirements of its efficient operation.

The approach presented here is not intended to be a final solution, but hopefully a basis on which to build. Two significant problems, which appear to have avoided even mention in previous work, have been recognized and solution approaches suggested. The fact that the performance of one activity can have an effect on the performance of others and that it is desirable to know at what level the affected activities may have operated without this effect has been pointed out. Also, the fact that an activity, even though it incurs only a small cost itself, may have a controlling influence on other activities or cost factors whose cost is significant was indicated. The following outline summarizes the methods discussed: (1) for selecting activities which play an important role in determining the overall performance of the manufacturing unit, (2) for obtaining an adjusted performance measure for each one based on its interaction with other activities, and (3) for assigning to each activity a weight proportional to the costs that it controls rather than those that it incurs.

(1) Select Activities

a. Determine which items within the manufacturing budget are activities whose performance affects overall manufacturing performance.

b. Select those which constitute the desired level of control - i.e., excluding those whose effect it is judged will fall in line when the others are operating properly.

c. Carefully define the scope of each activity to facilitate establishing its interaction with other components of the manufacturing system.

(2) Determining Interaction

a. Draw a flow diagram including all selected activities and those which affect their performance, indicating these effects with directed arrows.

b. On a two-coordinate plot indicate the expected behavior of the dependent activity as a response to changes in the affecting activity.

c. Calculate the adjusted performance of each activity by dividing its measured performance by a series of expressions representing the effects determined in Step 2b, above. For illustration purposes a simple linear relationship was used here.

(3) Combining Adjusted Performances

a. Draw a new flow diagram to include all of the selected activities and cost factors and establish their interrelationships on two-coordinate plots.

b. Calculate a controlled cost for each activity or factor based on its own cost, the costs it controls, and the portion of it that is controlled by other activities.

c. Let the weight of an activity be equal to the costs that it controls divided by the sum of costs controlled by all activities under consideration. Multiply the adjusted performance for each activity by its weight and add the results to obtain the overall performance measure of the manufacturing unit.

It is hoped that this outline and the reasoning behind it will provide a framework for further efforts which will narrow its application to specific types of manufacturing units. Also, additional research for the general approach could be most effectively applied in the following areas:

(1) Establishing an objective basis for selecting activities which contribute significantly to overall performance.

(2) Developing activity interrelationships based on statistical analysis of production data or utilizing controlled experimentation.

(3) Studying the feasibility of a linear programming approach to assigning weights to the activities.

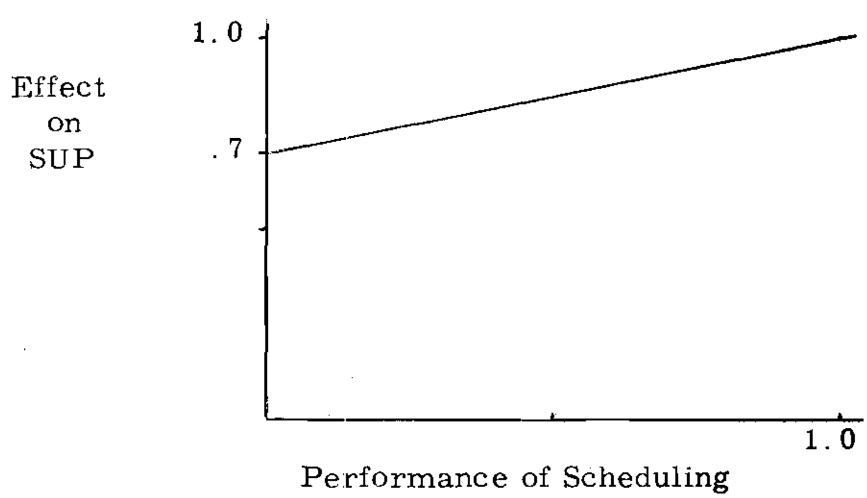
APPENDIX

Following are graphs and calculations for the completion of the example in the text of the thesis. The assumed performances for each activity within the manufacturing unit are found in the second column of Figure 10. The performance of Scheduling, an outside activity affecting the unit, is assumed to be 80 per cent. Incurred costs have been taken from the budget in Figure 3. The calculations are divided into two sections: Performance Control and Cost Control.

Performance Controlling Relationships

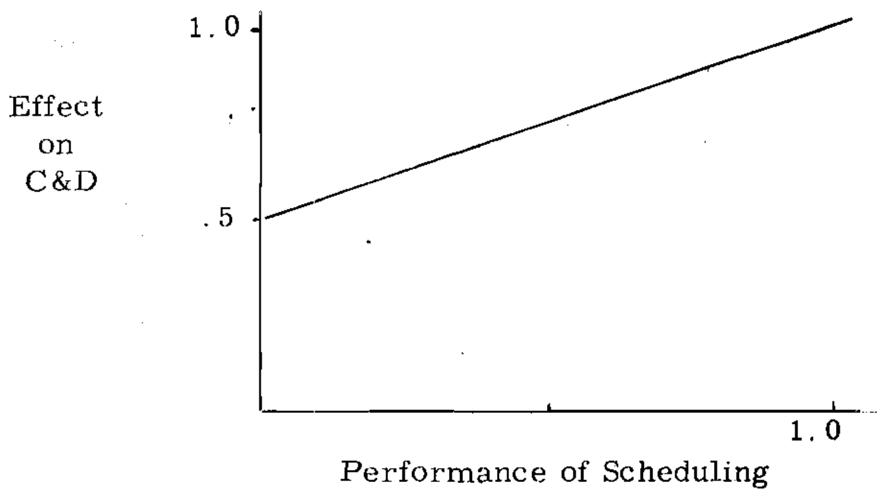
As seen from the diagram in Figure 8, the performances of the Supervision and Clerical and Dispatching activities are affected only by Scheduling, Materials Handling only by Supervision and Set-up by both Supervision and Clerical and Dispatching.

Supervision



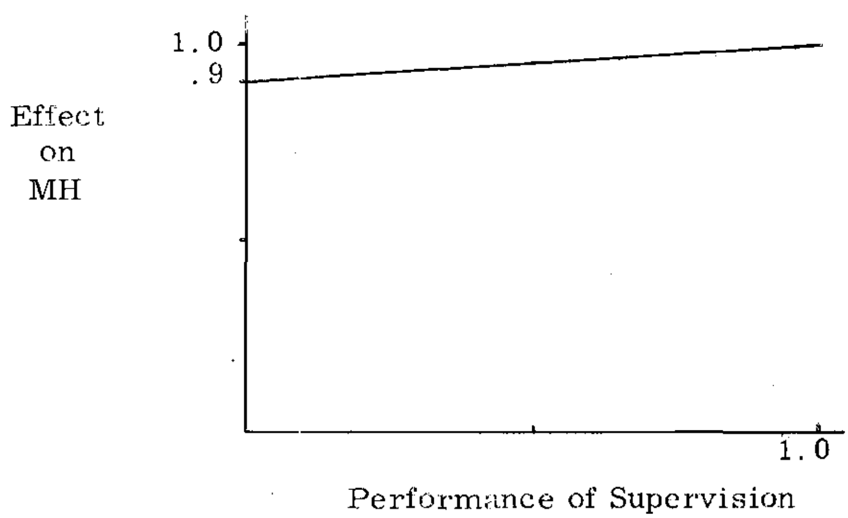
$$SUP_{adj} = \frac{.95}{1-.3(1-.8)} = 1.011$$

Clerical and Dispatching



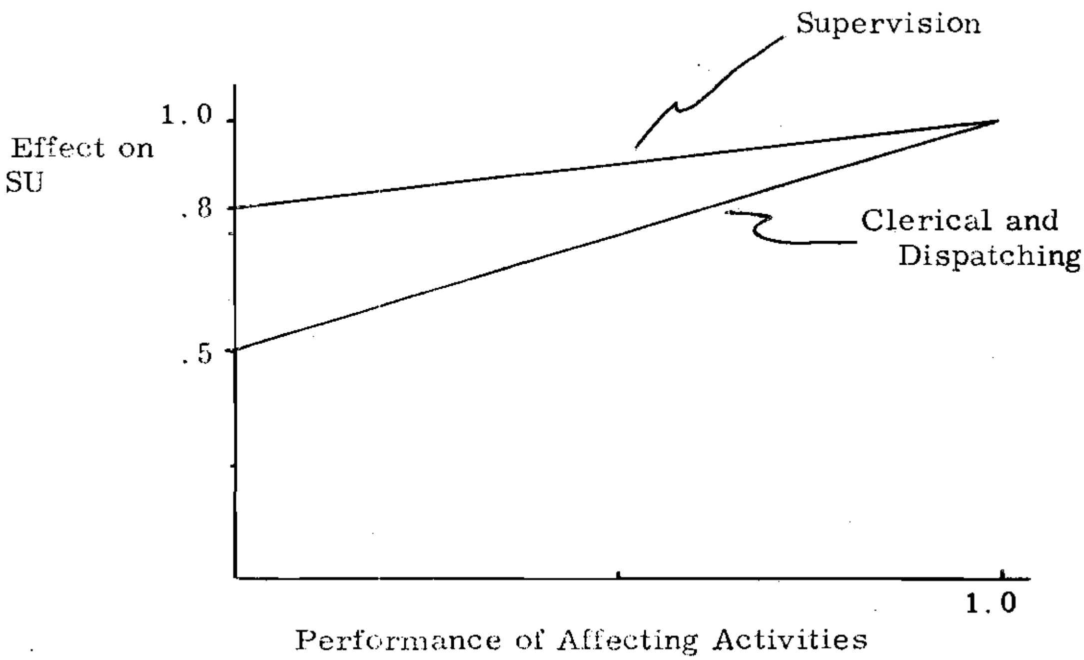
$$C\&D_{adj} = \frac{.75}{1-.5(1-.8)} = .833$$

Materials Handling



$$MH_{adj} = \frac{.75}{1-.1(1-.95)} = .754$$

Set-Up



$$SU_{adj} = .90 \left[\frac{1}{1-.2(1-.95)}\right]\left[\frac{1}{1-.5(1-.75)}\right]$$

$$= \frac{.90}{(.990)\ (.875)}$$

$$= 1.039$$

Cost Controlling Relationships

Recalling that one activity must take up the slack cost not controlled by others, it has been assumed that, in general, this slack will be assigned to the particular activity whose cost is being apportioned as a measure of self-control. The exception will be for the pure cost factor, Overtime Premiums, which can have no measure of self-control since it has no performance. In this case, the slack has been assigned to Direct Labor.

The general procedure in calculating controlled costs is to begin with those terminal activities or cost factors which control no others and work upward through the diagram in Figure 8. The table in Figure 11 at the end of the appendix aids in accumulating costs at the various levels. Beginning at the bottom with Inspection and Rework, controlled costs are entered along the row under the controlling activity or factor. As the costs accumulated at the lower levels are absorbed at higher levels, they are bracketed. After working all the way up the table, the unbracketed figures are added in each column. These totals represent the costs controlled by each activity and may be weighted according to their proportion of total controlled cost.

Inspection

As seen from the example in the text, Inspection controls no cost but a portion of its own. The remainder, 25 per cent, is controlled by the Scrap factor.

Controlled by Scrap - .25 (1100) = $825

Controlled by Inspection - .75 (1100) = $275

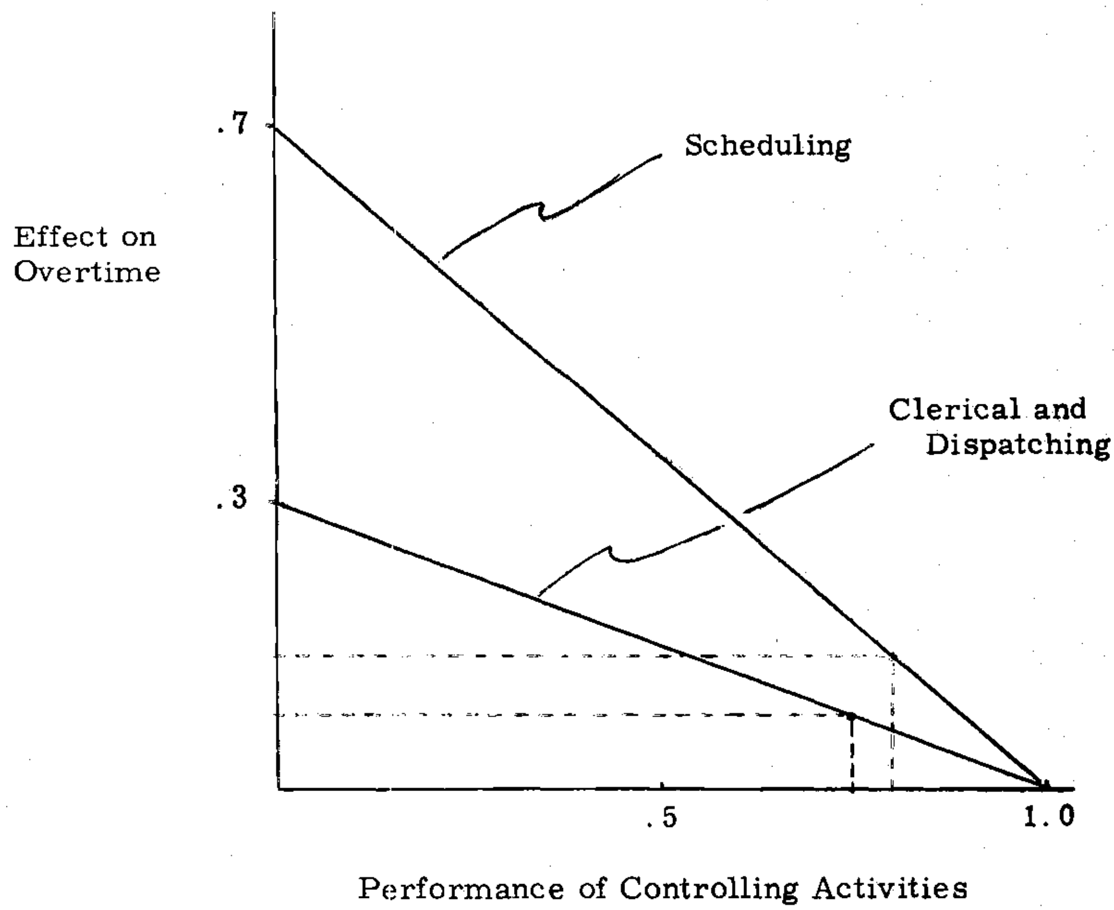
Rework

As above, Rework controls only 20 per cent of its own cost. The remainder is controlled by Scrap.

Controlled by Scrap - .80 (800) = $640

Controlled by Rework - .20 (800) = $160

Overtime Premiums



The remainder is controlled by Direct Labor.

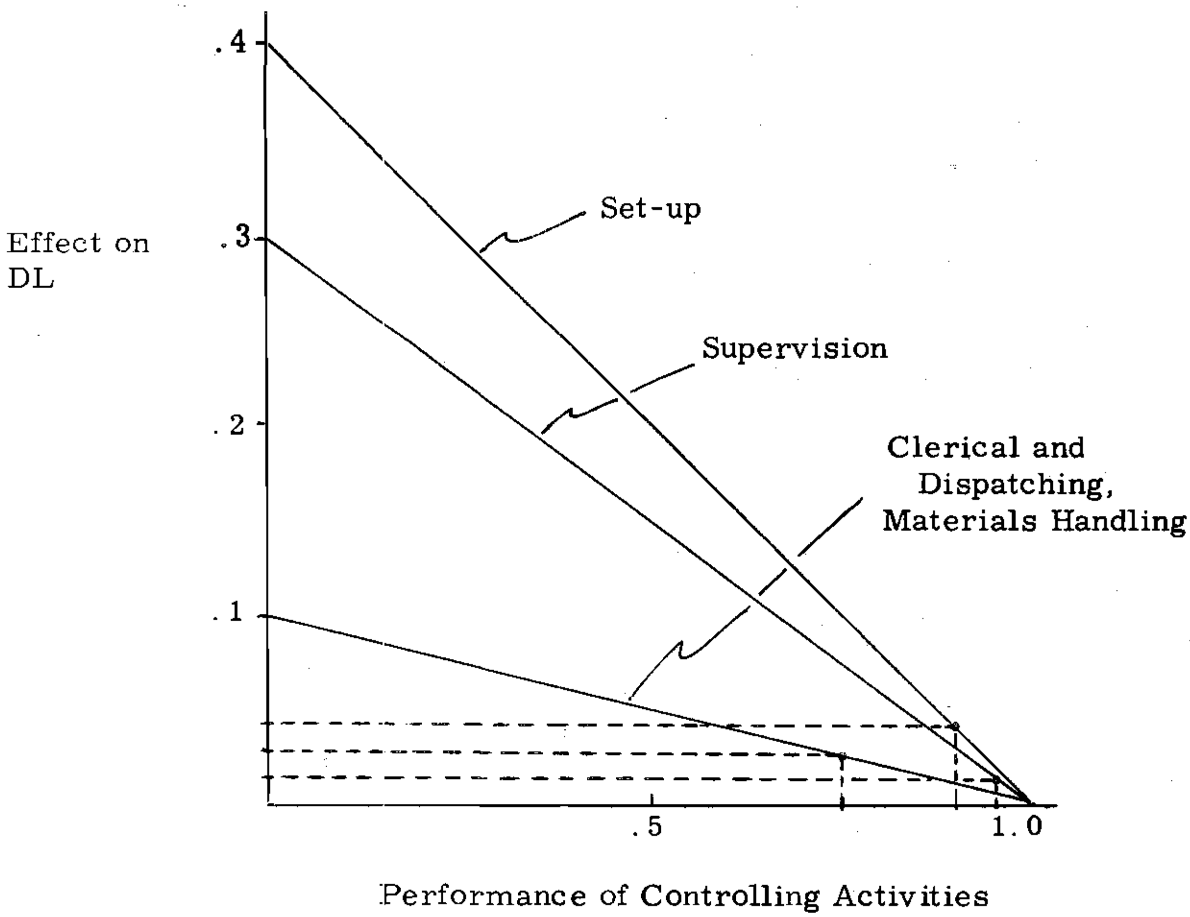
From the graph:

Controlled by SCH - .14 (3200) = **\$448**

Controlled by C&D - .08 (3200) = **\$256**

∴ Controlled by D. L. - .78 (3200) = **\$2496**

Direct Labor



Controlled by SU - .04 (12690) = $ 508

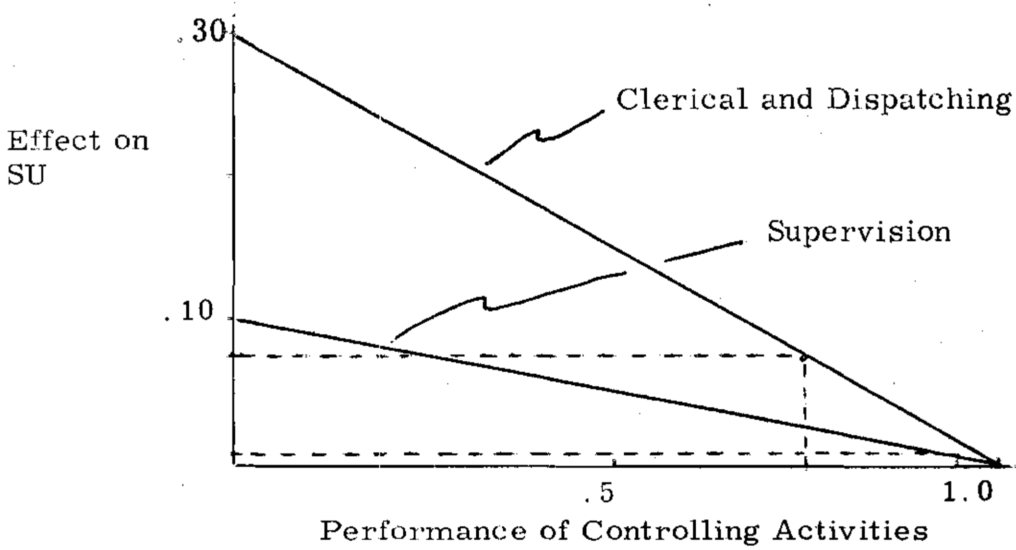
Controlled by C&D - .03 (12690) = 381

Controlled by MH - .03 (12690) = 381

Controlled by SUP - .02 (12690) = 254

∴ Controlled by D. L. - .88 (12690) = 11,167

Set-up

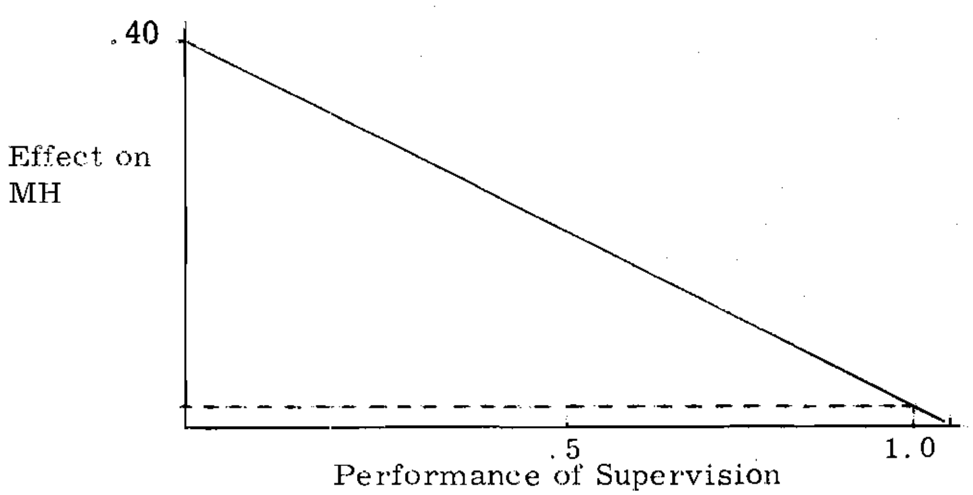


Controlled by C&D - .07 (2008) = $141

Controlled by SUP - .01 (2008) = $20

∴ Controlled by SU - .92 (2008) = $1847

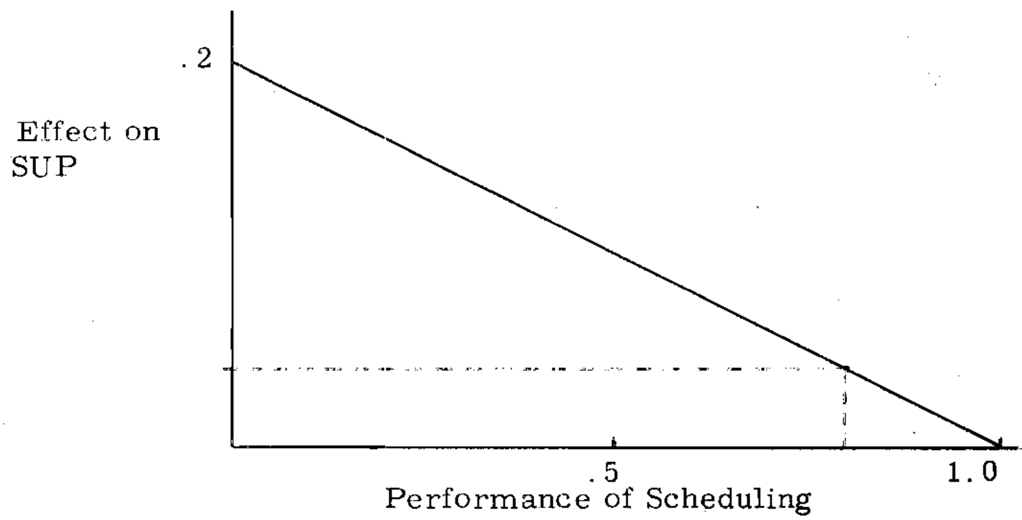
Materials Handling



Controlled by SUP - .02 (1181) = $24

∴ Controlled by MH - .98 (1181) = $1157

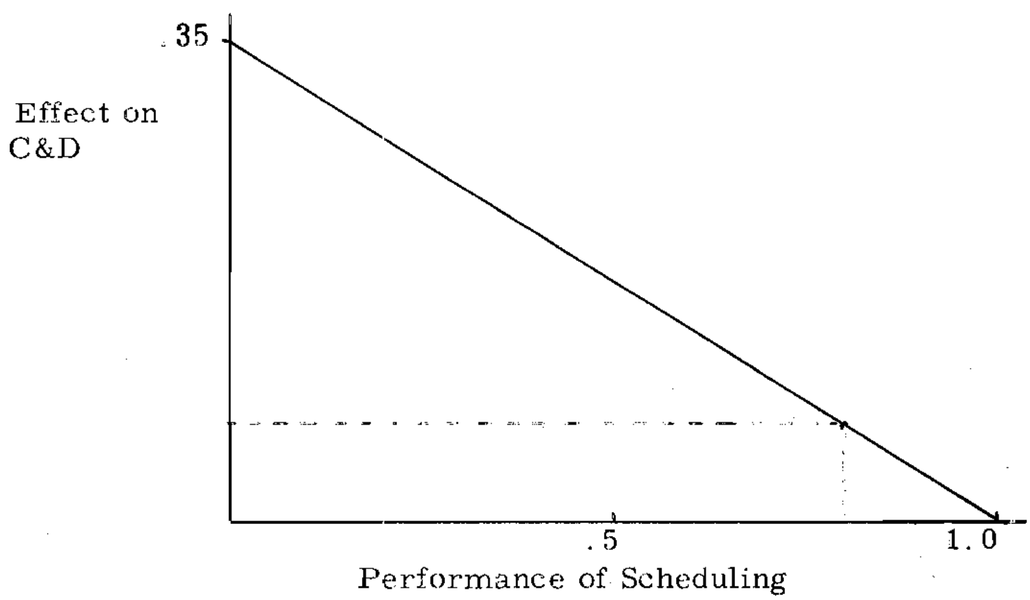
Supervision



Controlled by SCH - .04 (1898) = 78

Controlled by SUP - .96 (1898) = 1820

Clerical and Dispatching



Controlled by SCH - .07 (1327) = 93

Controlled by C & D - .93 (1327) = 1234

Controlled Activities	Incurred Cost	Accumulated Cost	Controlling Activities																			
			SUPERVISION		CLER. & DISP.		MAT. HAND.		SET-UP		DIR. LABOR		INSPECTION		REWORK		SCRAP					
			%	$	%	$	%	$	%	$	%	$	%	$	%	$	%	$	%	$	%	$
SUPERVISION	$1600.	$1892.	.96	1920.																		
CLER & DISP	550.	1327.			.93	1234.																
MAT. HAND.	200.	1181.	.02	(24)			.98	1157.														
SET-UP	1500.	2008.	.01	(20)	.07	(140.)			.92	1848.												
DIR. LABOR	10,000	12,6[illegible]	.02	(254)	.03	(371.)	.03	(381.)	.04	(508.)	.88	11,166.										
OVERTIME	3200.	3200.			.08	(256.)					.78	(2496)										
SCRAP	300.	1215.									.16	(194.)										
INSPECTION	1100.	1100.											.15	825.			.25	(175.)				
REWORK	800.	800.													.20	160.	.80	(640.)				
Controlled Cost				1820.		1234.		1157.		1848.		11,166.		825.		160.						

Figure 11 - Cost Control Table

BIBLIOGRAPHY

References Cited

(1) Richards, Max C. and Greenlaw, Paul S., Management Decision Making, R. D. Irwin, Homewood, Illinois, 1966.

(2) Gold, Bela and Kraus, Ralph M., "Integrating Physical with Financial Measures for Managerial Controls," Academy of Management Journal, June 1964.

(3) Notably the duPont return on investment calculation as discussed in Chapter 27 of:

Amrine, H. T., Ritchie, J. A. and Hulley, O. S., Manufacturing Organization and Management, Second Edition, Prentice-Hall, Englewood Cliffs, New Jersey, 1966.

(4) Martindell, Jackson, The Appraisal of Management, Harper and Row, New York, 1962.

(5) Churchman, C. W., Ackoff, R. L., and Arnoff, E. L., Introduction to Operations Research, John Wiley and Sons New York, 1957.

(6) Forrester, Jay, Industrial Dynamics, M. I. T. Press Cambridge, Massachusetts, 1961.